ESL-TR-99/01-01

Development of Energy-Efficient Housing for Low-Income Texas Residents

Funded by

Center for Energy and Mineral Research

Texas A&M University

Progress Report

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Introduction.

The purpose of this Center for Energy and Mineral Research (CEMR) funded study is to improve the energy use in low-income housing in the State of Texas. This study aims at achieving energy-efficiency by using a combination of measured data and calibrated building energy simulations to verify appropriate energy-efficient measures.

The objectives of the research initially include the choosing and instrumenting a low-income residential house in the Bryan and College Station area to serve as a baseline reference for energy analysis. This includes polling (the process of collection of data), archiving, and analyzing energy use, internal, and environmental data collected from the house. A calibrated building energy simulation of the instrumented house will use these internal and environmental measurements and the careful documentation of the house to analyze energy conservation measures. This project has successfully accomplished its goal of selecting and instrumenting a baseline Habitat for Humanity house. Monitoring of the 26 channels of 15-minute data began in March 1998 and has continued through December 1998.

The energy and environmental data from the house will also be made available to faculty and students in the College of Architecture by posting the data on an ftp server. This will enhance students architectural design studios creating a refined understanding of the energy use of an occupied house.

Overview of current work or research relevant to the issue or problem.

Habitat for Humanity is a non-profit, Christian-affiliated ecumenical housing group that helps build low-income housing in the United States and other countries. Habitat aims at increasing the ability of families to buy a home by giving low interest rates, requiring low down payments and providing payment subsidies. The Habitat model functions appropriately because the intended occupant of the house provides "sweat equity," through contributing 300-500 hours of volunteered time during construction. Habitat for Humanity provides the owner with an interest free loans where mortgage credit is not possible. The organization sells these houses at no profit. Habitat for

Humanity has been very successful in providing low-income housing for many communities using this model of operation.

This CEMR-funded effort has built on the results of previous efforts to improve low-income housing in Texas and Florida. Previous tests performed on two side-by-side Habitat for Humanity hoses in Houston by researchers at Texas A&M University examined the potential for improving low-income housing. The Houston study included improved envelope insulation and shell tightening, window upgrades and the introduction of an efficient HVAC system. Using side-by-side measurements of identical houses and a calibrated building energy simulation, the results showed that most of the energy conservation measures performed as estimated when the confounding factors of weather conditions, different life styles and omissions in the construction of the houses were removed using the simulation (Bou-Saada et al., 1998). Results showed a reduction of 11% in the annual electricity use and 0.8% in the annual natural gas use.

Studies on eight monitored Habitat for Humanity low-income houses in Florida that had a series of retrofits showed an average of 14% reduction (2100 kWh) of annual energy use (Parker et al., 1998). These measures included return duct sealing, solar water heating, low-flow shower heads, refrigerator coil cleaning and compact fluorescent lighting. A similar study carried out on 190 Habitat for Humanity houses in Homestead, Florida was also found to be very successful in improving energy use. (Parker and Mazzara, 1996). Both the Florida and Texas studies indicate that energy can be saved in low-income housing by transferring technologies developed and used by the housing stock of the middle and upper income classes of society. This CEMR-funded research has taken the state of art in residential energy conservation one step further by verifying which retrofits work with the monitoring 23 channels of energy and environmental data. An added feature over all other studies is simultaneous assessment of energy conservation measures and their effects on indoor air quality (IAQ) issues through the monitoring of indoor-outdoor CO_2, relative humidity and temperature.

Accomplishments of the Research.

During the first year the following tasks have been accomplished:

1. The selection of a Habitat for Humanity house for careful instrumentation and documentation was performed with the assistance of Ms. Patricia Burke and Dr. Jim Davis of the Bryan/College Station Habitat for Humanity office.

2. The purchase, design, and installation of equipment and instrumentation for the continuous monitoring of 15 minute data from the house. This equipment measured the energy use of the house, on-site weather parameters (temperature, relative humidity, solar radiation, wind and CO_2 concentrations), and indoor conditions (temperature, relative humidity and CO_2 concentrations). Equipment performance for the house was also measured.
3. The development and use of automated polling routines to allow for weekly data collection and graphical inspection of the data.
4. Recording and archiving of the data in a contiguous data base for later analysis.
5. Measurement of the tightness of the building with a blower-door test.
6. Measurement of the duct airflow with a velometer
7. Development of a preliminary DOE-2 building energy simulation model of the case-study house.

Significant findings of the research.

The Habitat for Humanity house is constructed too tight. This is discovered by a combination of blower door tests and continuous indoor-outdoor CO_2 concentrations. Experiments with forced ventilation rates will are recommended to further study the problem.

1. Heat gain from the attic could be large than expected. The attic temperature in the summer routinely reaches 130°F during sunny days. This puts excess loads on the air-conditioning unit through the ductwork. Use of computer simulations and additional spot measurements with portable data loggers will enable further study this effect.

2. The thermal mass of the concrete floor slab is significant. This has a damping effect on the indoor temperature. There are also a slight differences in temperatures between center the of the slab and the edges of the house. The impact of this will be further studied using computer simulations.
3. Energy use from the lighting and receptacles was found to be large. This contributes to high utility bills and increases the load on the air-conditioning unit. Alternative, low-cost high efficiency lighting will be investigated including compact florescent lights and the potential use of daylighing.

Potential areas for saving energy and/or improving IAQ.

The first year of monitored data enabled the identifying the following potential design changes.

1. The reduction of the summer time heat gain through the air-conditioning duct system. Measured temperature differences between the attic and the air-conditioning supply air is in the range of 80°F. This indicates that ducts are exposed to high heat gains that increase cooling loads. Future designs would seek to reduce these loads.
2. The installation of energy high efficiency air-conditioning unit. The present Habitat for Humanity house unit has a SEER of 10. Future recommendations will include using a SEER of 12 or higher which would decreases the annual cooling by 7-10%.
3. Determine how to increase the use of compact fluorescent lights. It is estimated that this would reduce the annual electricity cost by $50/year.
4. Improved ventilation and/or fresh air supply. Measurements from the current house indicate that house is too tight and it has many hours per day when CO_2 levels exceed 1500 ppm. (1000 ppm. is the recommended maximum by American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)). Future efforts would include designing and testing a forced ventilation system.
5. Relocation and isolation of the Domestic Hot Water heater (DHW). The baseline Habitat for Humanity house has an exposed domestic hot water heater (DHW) in the utility room with its 3” flue that contributes 0.1 ACH to the house’s overall tightness.

Isolating the DHW in a sealed cabinet (open to the attic for combustion) would reduce unwanted infiltration, eliminate potential CO problems, and further tighten the house.

Description of the plan to seek outside funding.

Supplemental funding of $680 requested for 1998/1999 has been requested and granted by the Texas A&M University College of Architecture to extend the monitoring for another year.

The following options will also be used to seek outside funding;

1. Contact the Energy Foundation, the energy efficiency agency of the Ministry of Energy in Ghana to use the information to develop energy-efficient housing for Ghana.
2. Apply to the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) for a Grant-in-aid, and to the University of California, Berkeley - Vital Signs group for sponsorship.
3. We are also planning on re-submitting to the CEMR for additional funding to select instrument and monitor a prototype low-energy Habitat for Humanity house.
4. Publish papers in peer-reviewed journals.
5. Work with the Habitat for Humanity organization to publicize the findings.
6. Show work to visitors and to other funding agencies.
7. Additional funding sources will be identified and contacted. They include;

   The Alliance to Save Energy, the United States Department of Energy (DOE), Department of Housing and Urban Development (HUD), the Texas State Energy Conservation Office (SECO), the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE), and the National Association of Home Builders (NAHB).

References

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Appendix 1. Pictures of the Habitat for Humanity house
at 1026 Commerce Street, Bryan, Texas

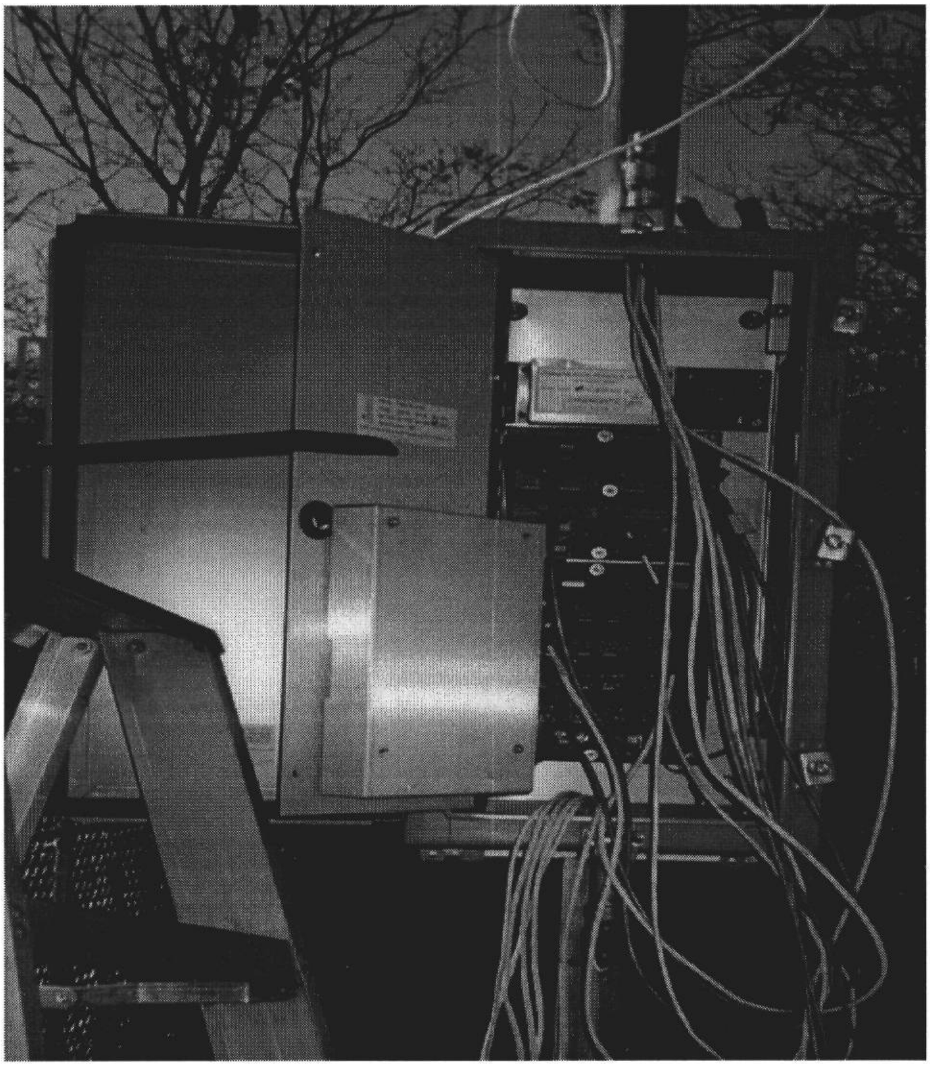

Photo1: The Data Acquisition System

The system used for data acquisition is a C180E Synergistics data logger. This can collect and store data from 50 channels (analog, power and digital). The Data Acquisition System (DAS) is located in the yard of the house. The sensors in the house are connected to the house by a 2" buried conduit. This photo shows the DAS during the installation

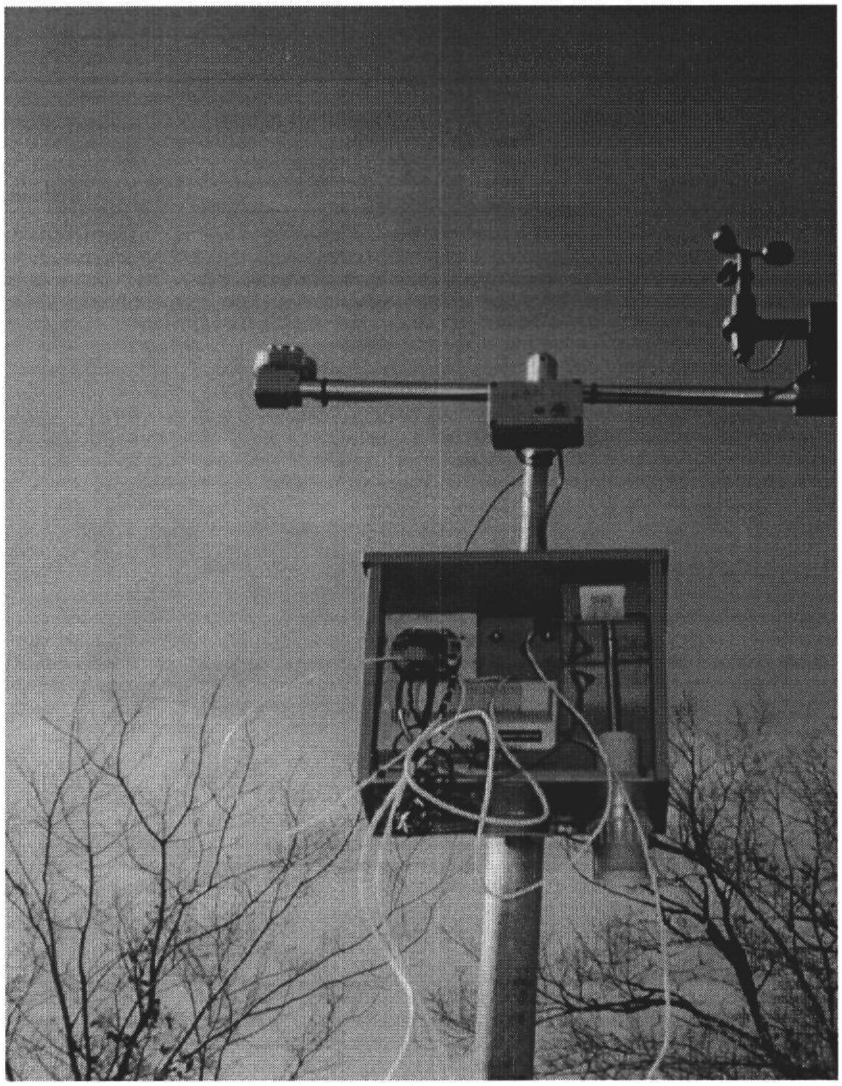

Photo 2: **The Weather Station**

The weather station is mounted above the data logger allowing on site measurements of temperature, relative humidity carbon dioxide concentrations, solar radiation and wind speed to be made continuously.

Photo 3. Sensors in the Attic

This photo shows the Vaisala temperature-relative humidity sensor that is used to measure conditions in the attic. The sensor is placed inside a protective radiation shield to prevent false readings from exposure to hot surfaces in he attic.

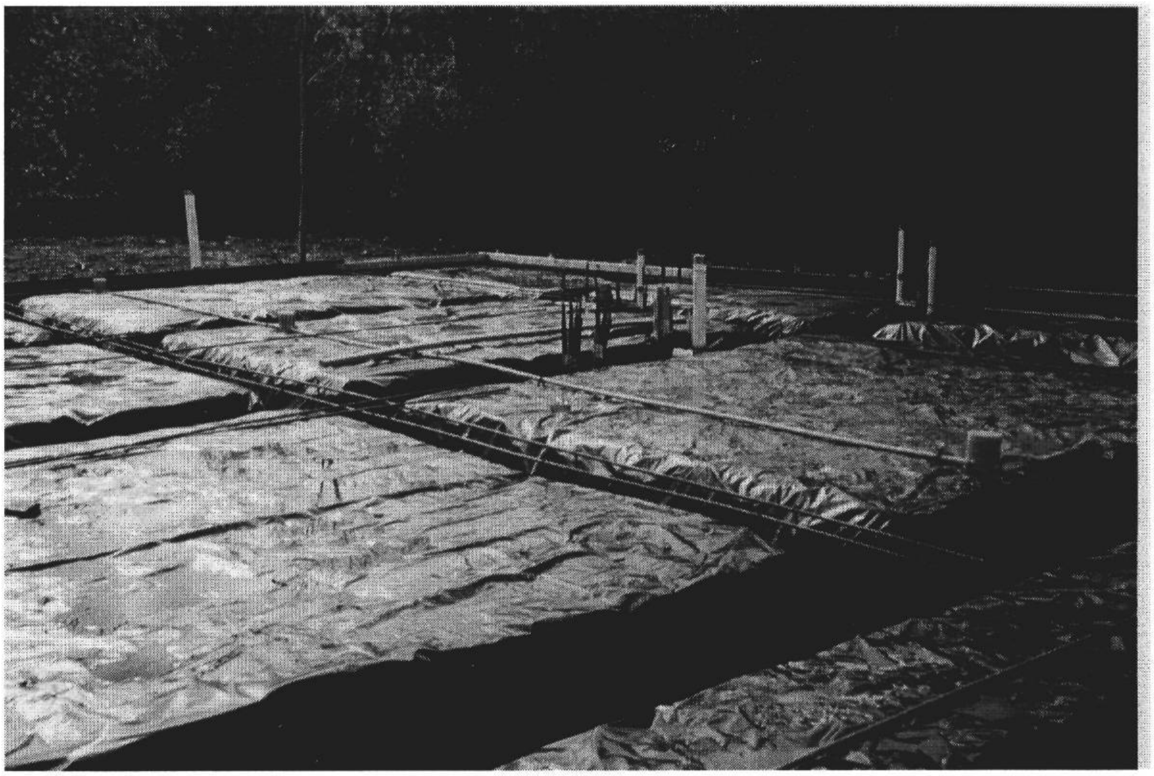

Photo 4: **Ground Temperature sensors**

Three resistance thermal devices (RTDs) are installed below the slab into the ground to record ground temperature below the slab. One sensor is located 2-4 feet from either edge of the house and in the third is located in the center of the house. The PVC canisters were placed in the floor slab and connecting conduit to facilitate access to the soil beneath the slab after the floor was poured. 2-wire RTDs were used to measure the ground temperature.

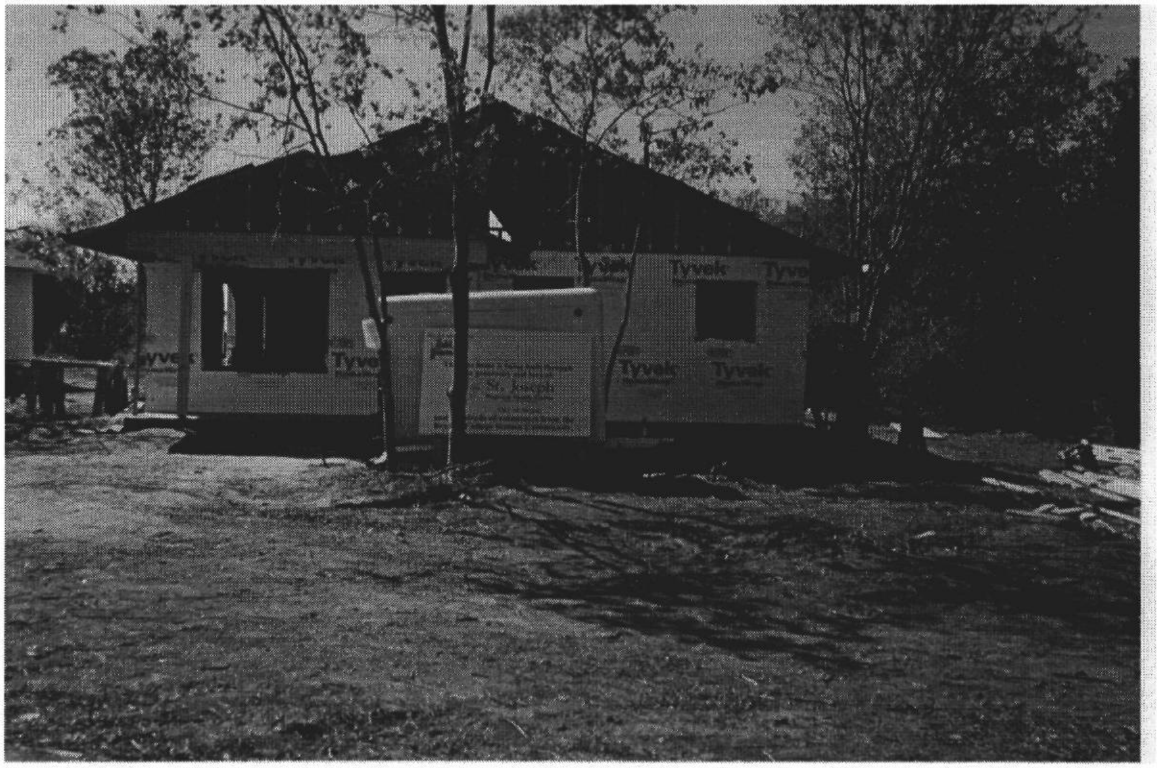

Photo 5: The construction of the case study house.

The wall construction of the house is vinyl siding, 1/2' plywood, 2" x 4" stud walling, blown-in cellulose insulation and drywall. The house is a concrete slab-on-grade construction with vinyl floor tiles. The ceiling is constructed of 1/2" gypsum ceiling panels and 6" blown insulation. The roof construction consists of 2"x 6" trusses with 3/4" plywood boarding and roof shingles.

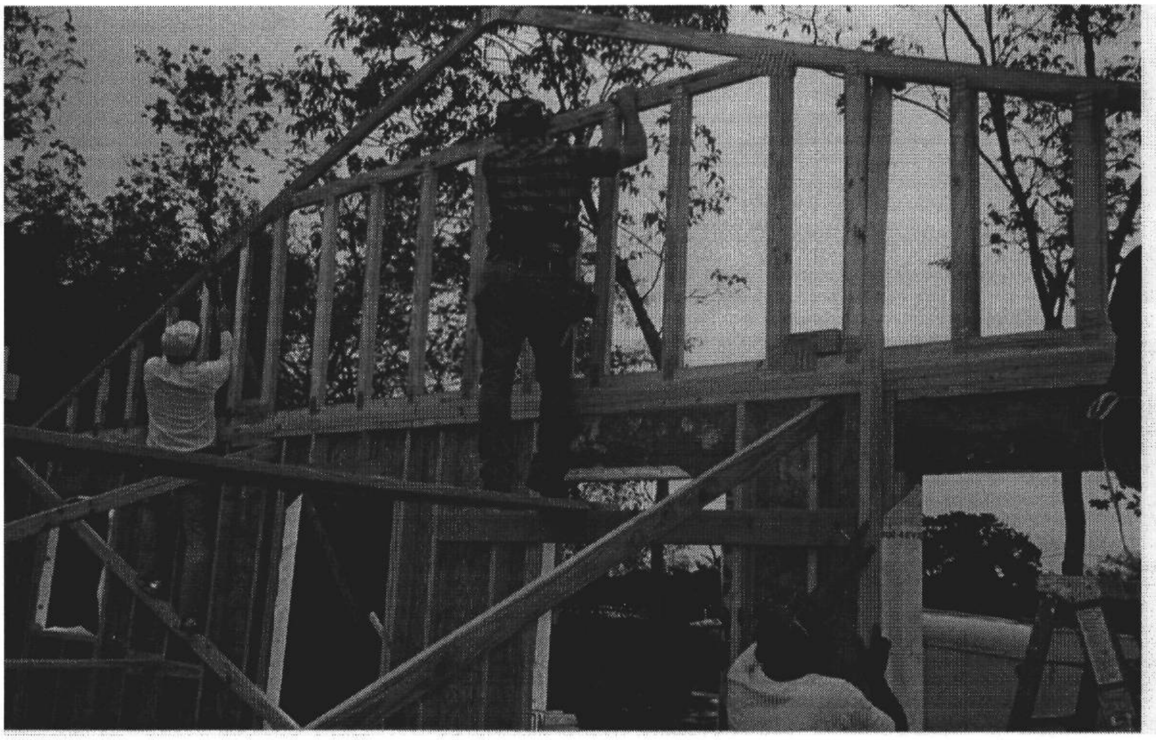

Photo 6: The construction of the case study house.

Construction of the Habitat houses is accomplished primarily with volunteer labor. Here workers are seen tilting the attic wall into place.

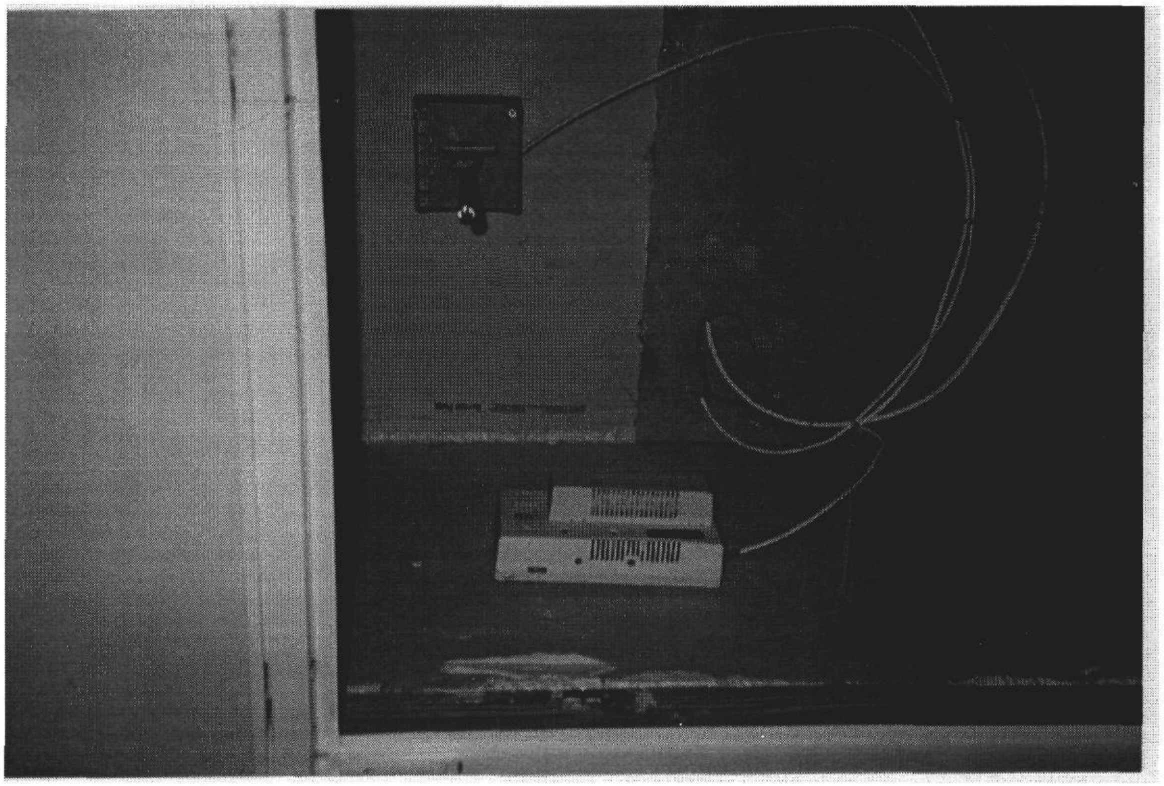

Photo 7: The indoor environmental condition sensors

Sensors located in the return air duct of the house measure indoors environmental conditions. A Vaisala HMD70 sensor measures the temperature and relative humidity and, a Telaire CO_2 sensor measures carbon dioxide concentration in the house.

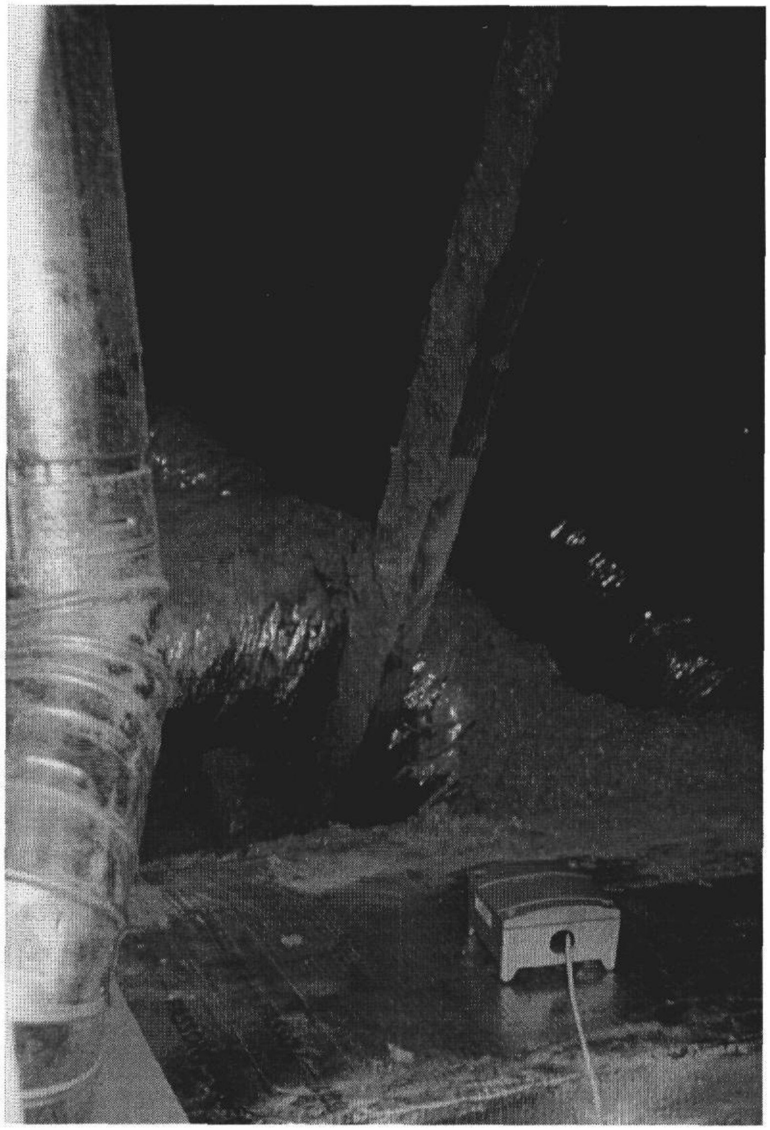

Photo 8: Supply air temperature and humidity sensor

This Vaisala HMD 70 has been inserted into the supply air duct of the house and gives continuous temperature and humidity readings of air from the air-conditioning unit

Appendix 2. Sample weekly plots for the Habitat for Humanity house at 1026 Commerce Street, Bryan, Texas for the week 7/28/98 to 8/3/98

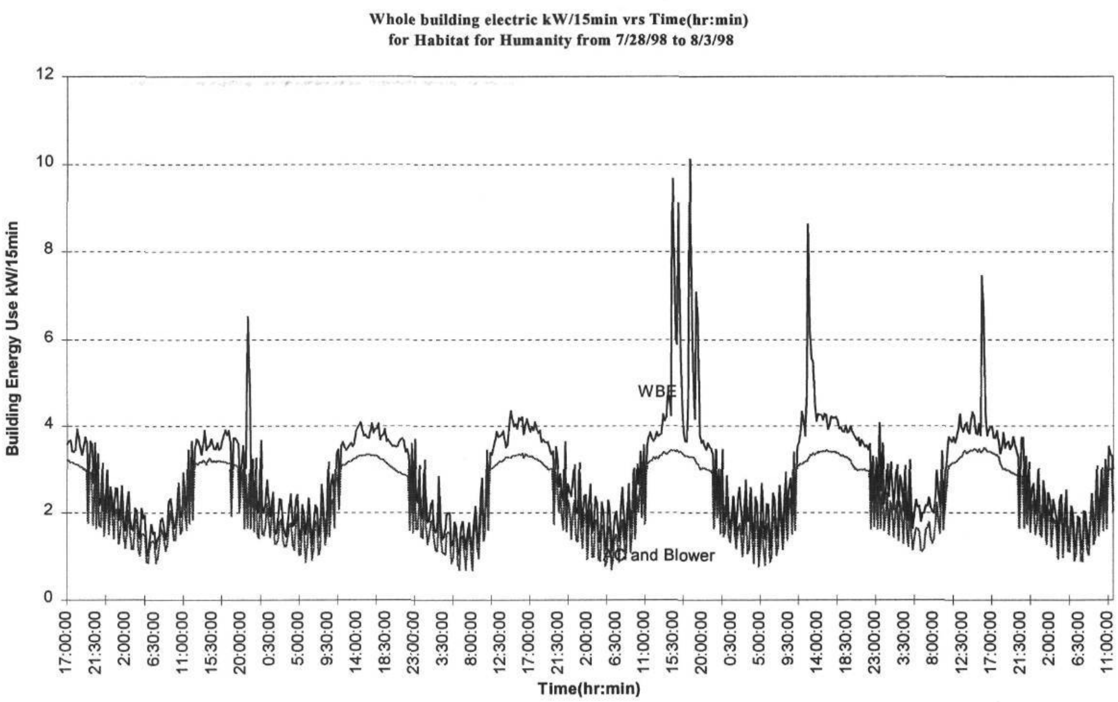

Fig.1. This is the pattern of energy use for one week at the Habitat for Humanity house. This shows the whole building electric use and the air-conditioning electric use for one week duration. These measurements are taken with current transducers in the electric distribution panel

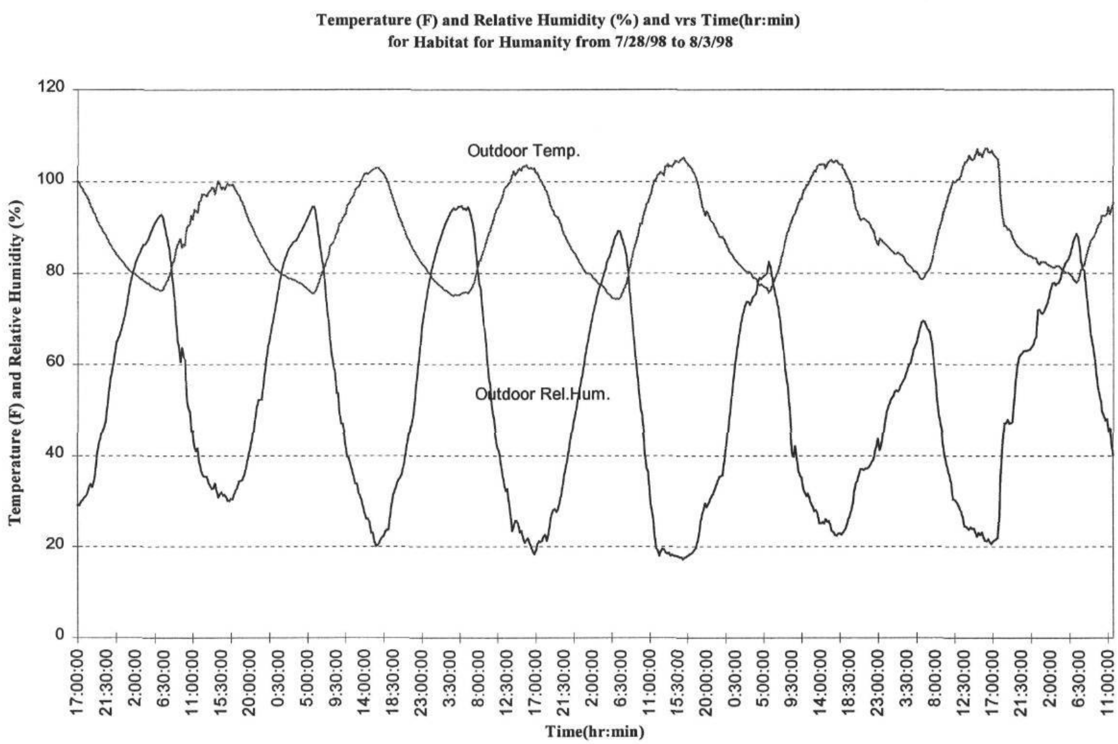

Fig.2. Outdoor temperature and relative humidity measurements for one week at the Habitat for Humanity house. These measurements are taken with a Vaisala HMD70 temperature / relative humidity sensor

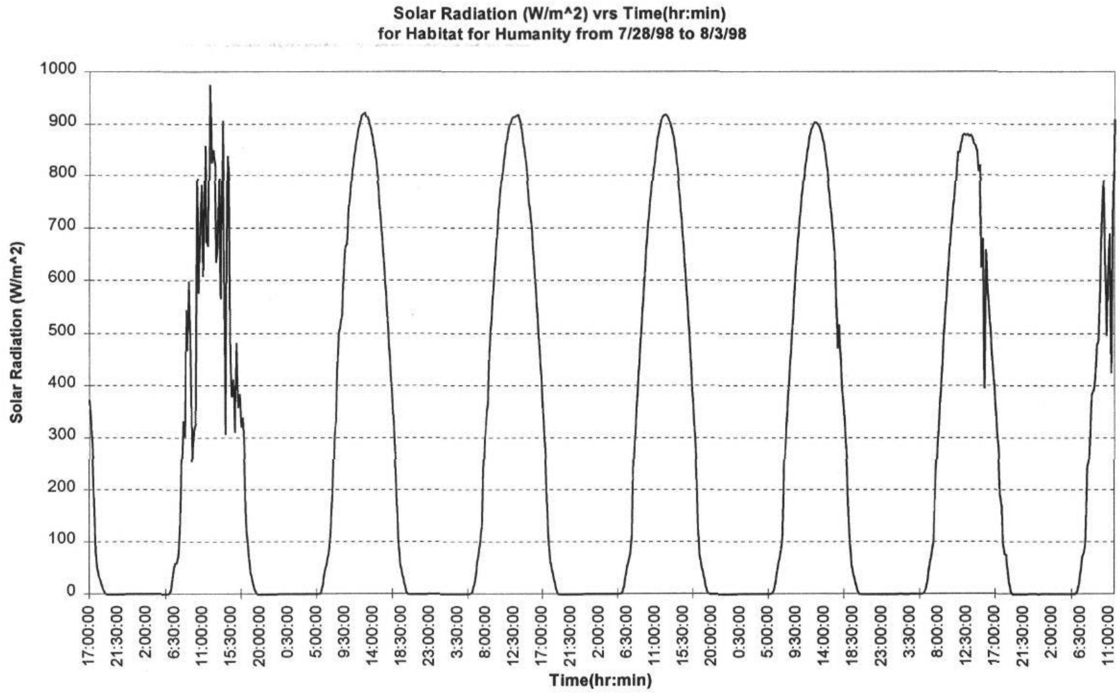

Fig. 3. Solar radiation measurements for one week at the Habitat for Humanity house. The radiation is measured using a Licor solar sensor. This sensor was calibrated against an Epply Spectral Precision Pyranometer located on the solar test bench on the Langford Architecture Center building A, Texas A&M University.

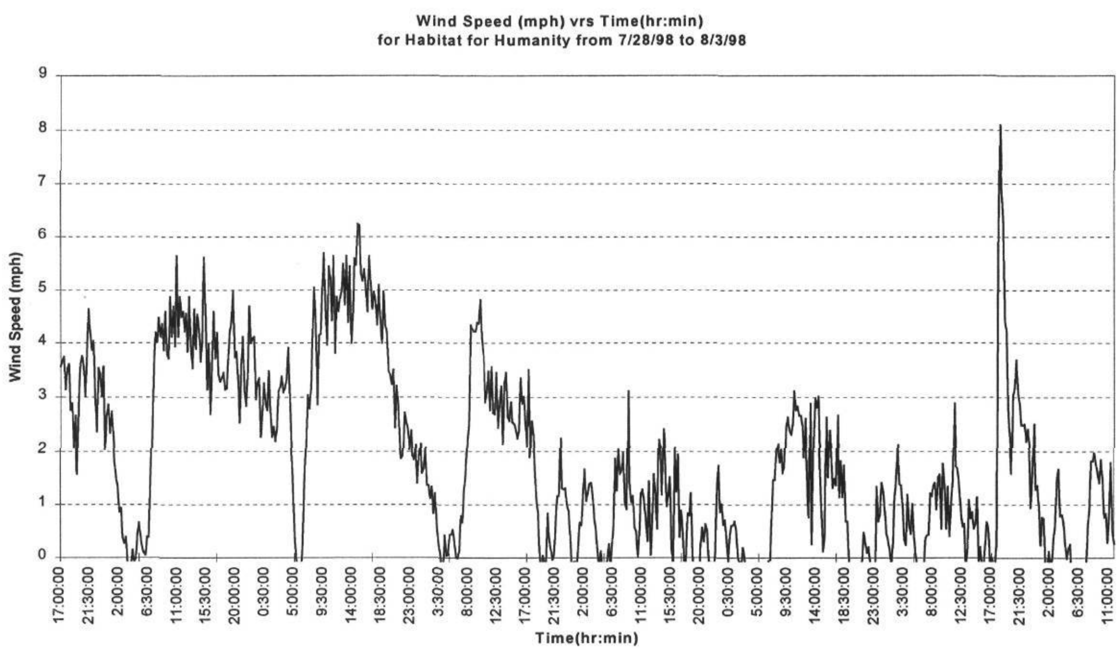

Fig. 4. Wind speed measurements for one week at the Habitat for Humanity house. These measurements are taken with a wind sentry 3-cup anemometer at the on-site weather station.

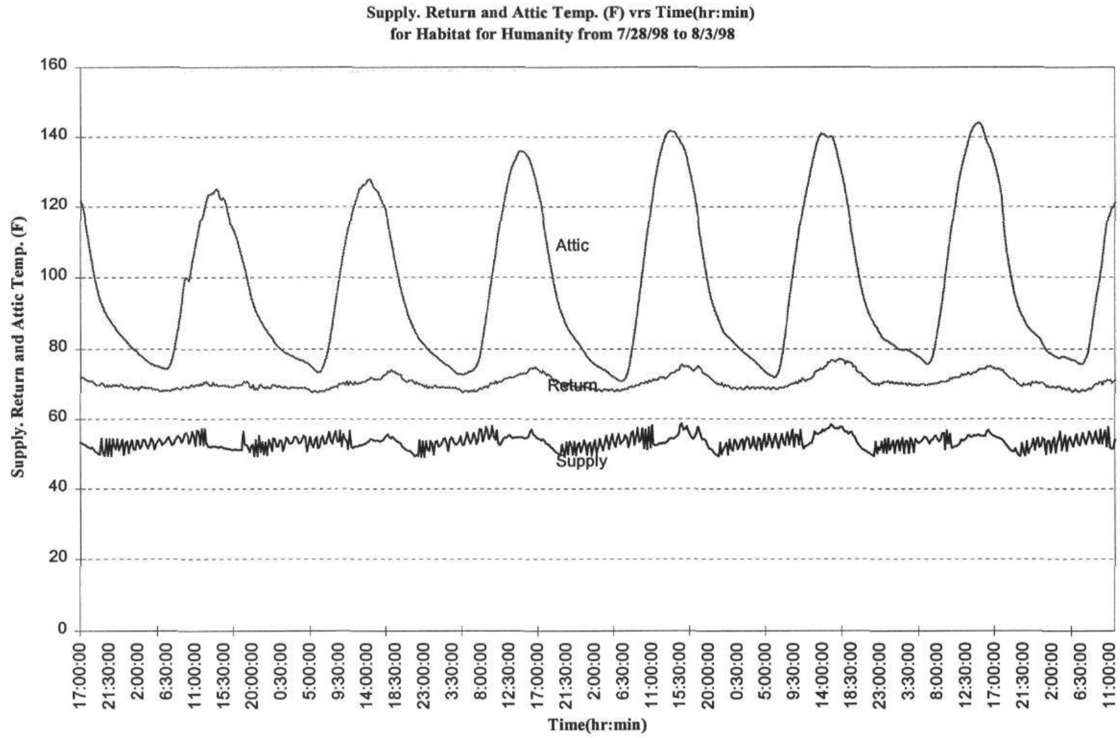

Fig.5. Supply, return and attic temperatures for one week at the Habitat for Humanity house. The air-conditioning unit maintains a temperature difference of approximately 10 °F between the return and the supply air. The graph shows that the unit has been cycling for long periods during the week. The attic temperature during this period was very high. These conditions put considerable strain on the equipment.

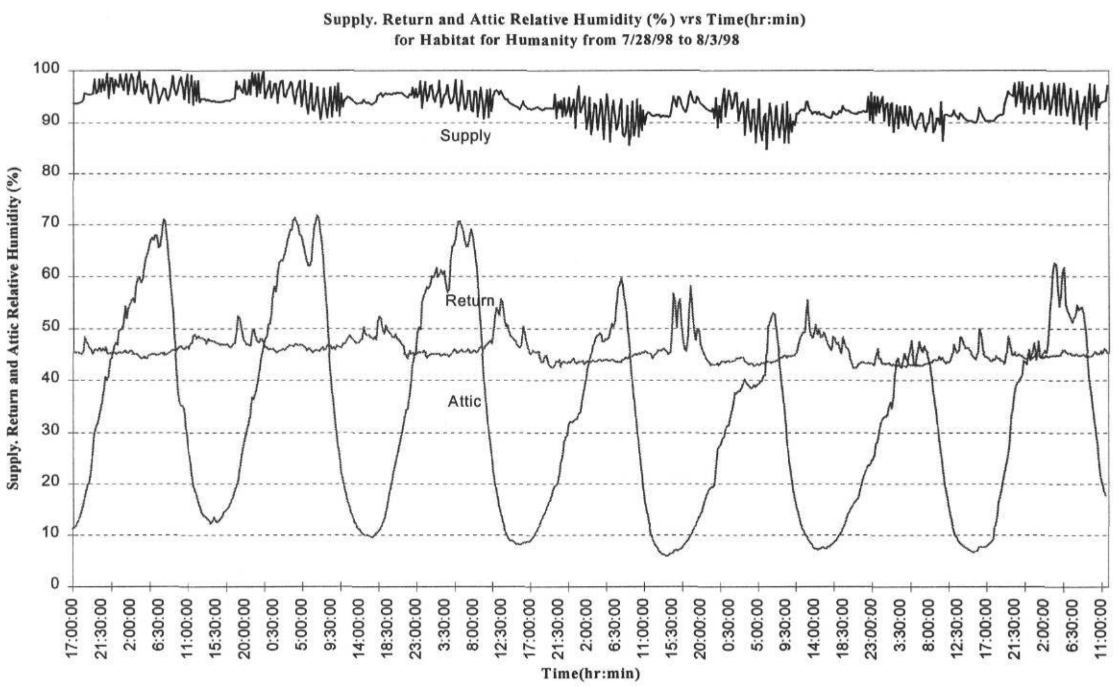

Fig.6. Supply, return and attic relative humidity for one week at the Habitat for Humanity house. These measurements were made with a Vaisala HMD 70 temperature relative/ humidity sensor.

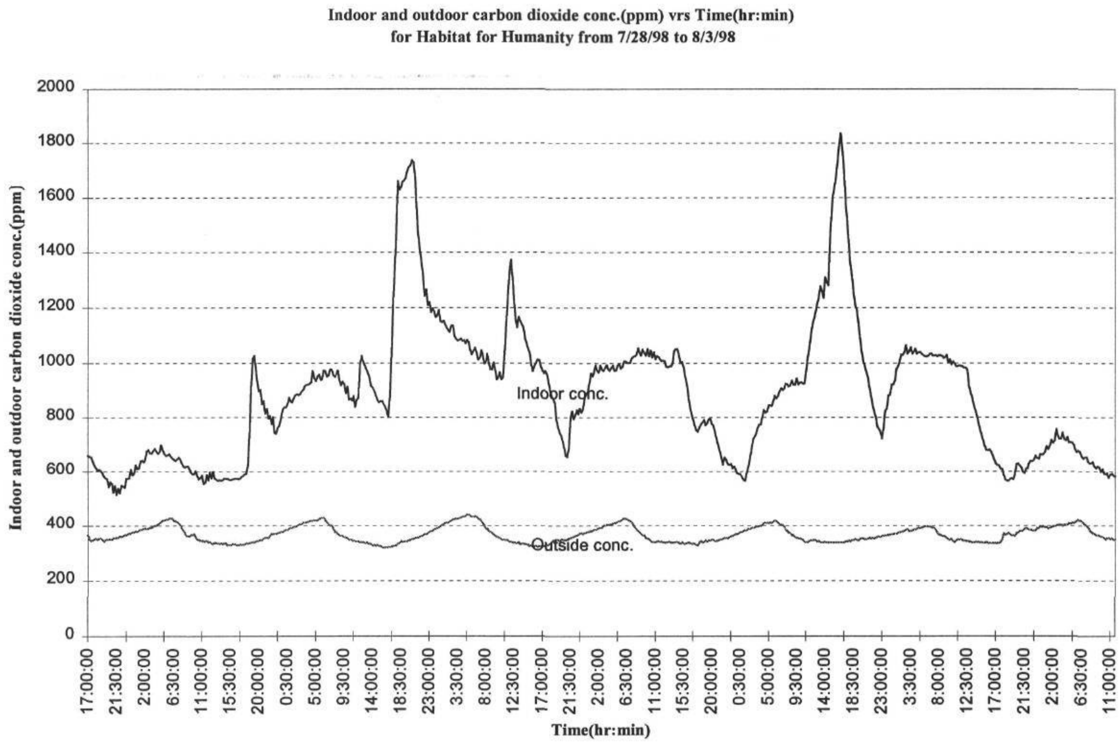

Fig. 7. Outdoor and indoor CO_2 measurements for one week at the Habitat for Humanity house. These measurements are taken with a calibrated Telaire 1071 CO_2 sensor.

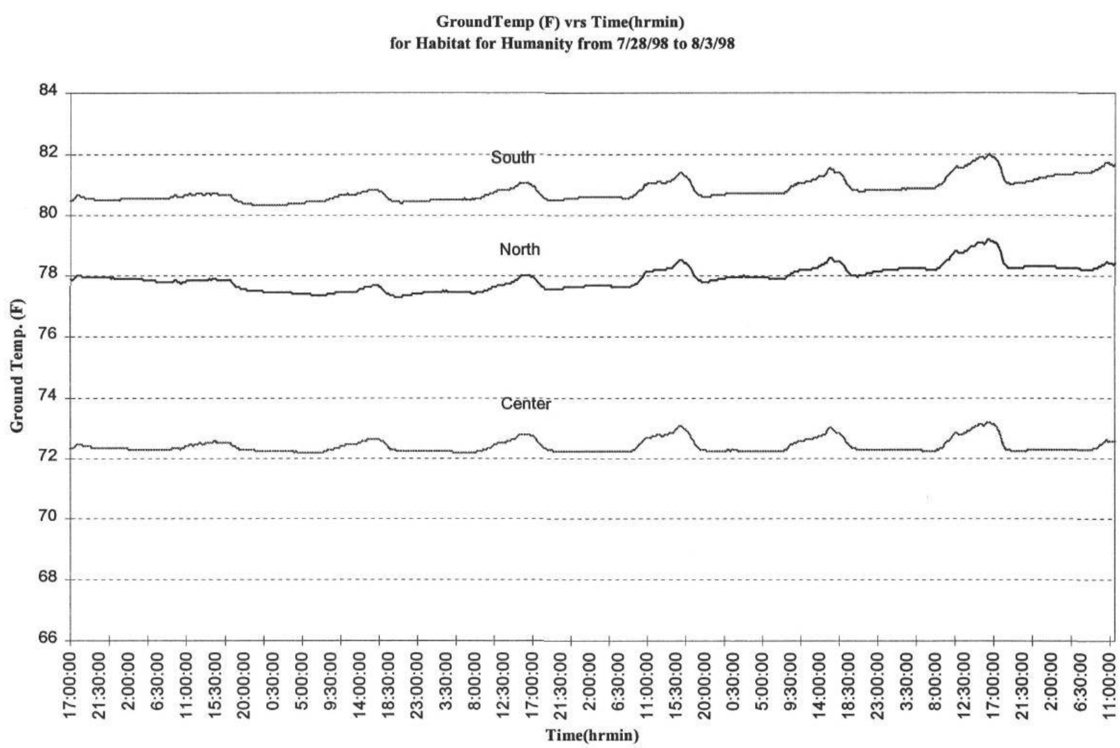

Fig.8. Ground temperatures measurements for one week at the Habitat for Humanity house.

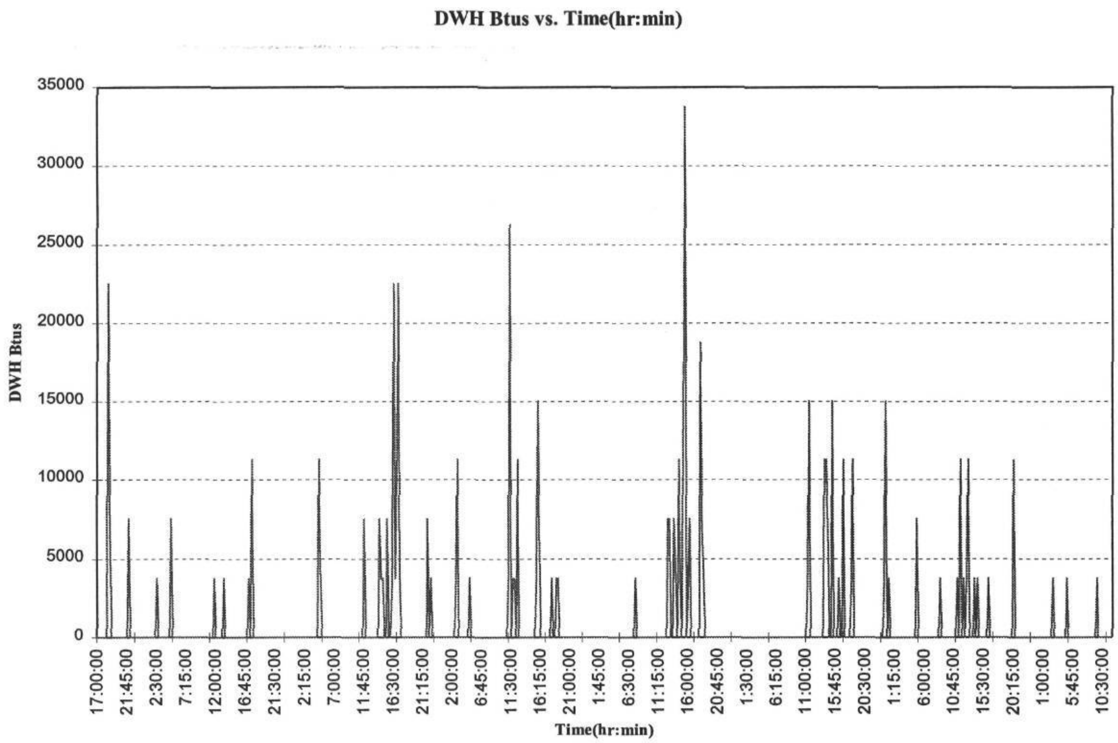

Fig. 9. Btu measurements for the domestic hot water heater for one week.

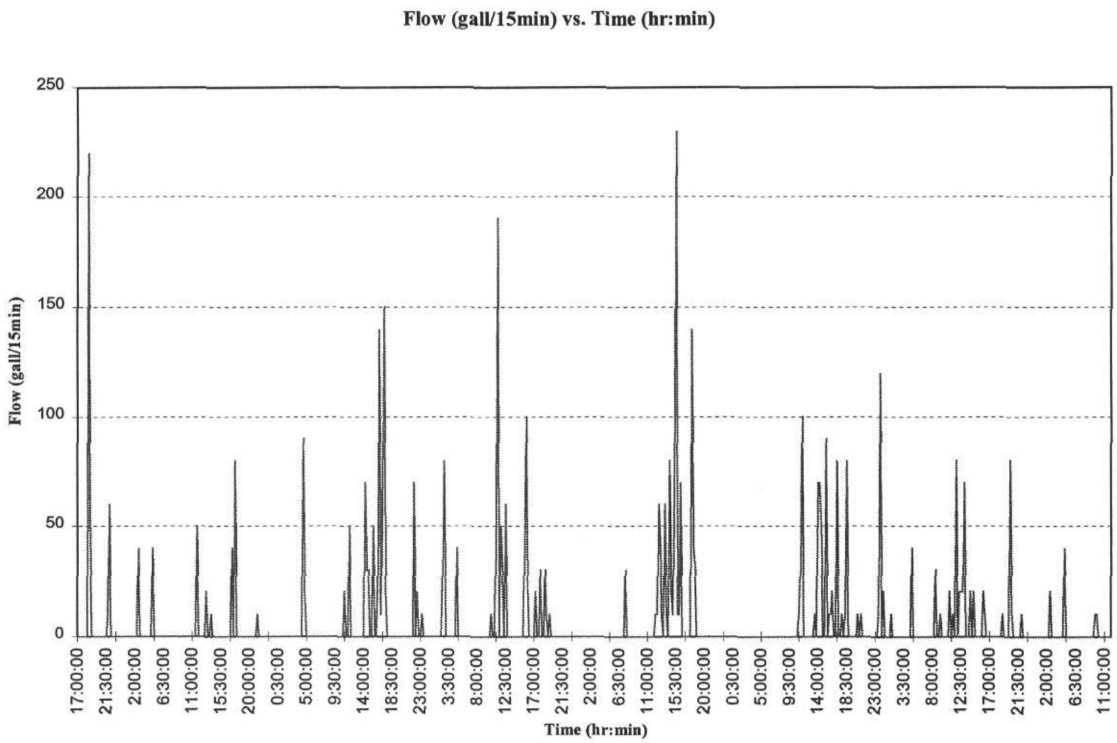

Fig. 10. Flow measurements for the domestic hot water heater for one week.

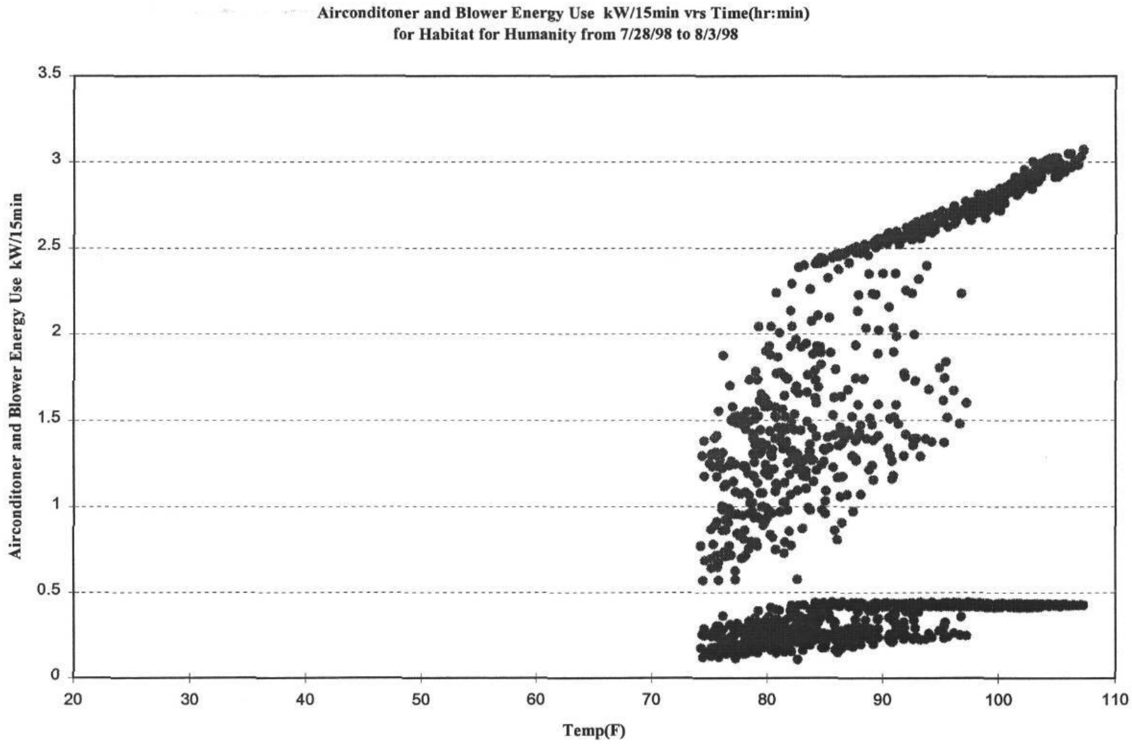

Fig. 11. Combined air-conditioning and air-conditioner blower energy use versus outdoor temperature and one week at the Habitat for Humanity house.

Appendix 3. Sample weekly plots for the Habitat for Humanity house
at 1026 Commerce Street, Bryan, Texas
for the week 12/29/98 to 1/5/99

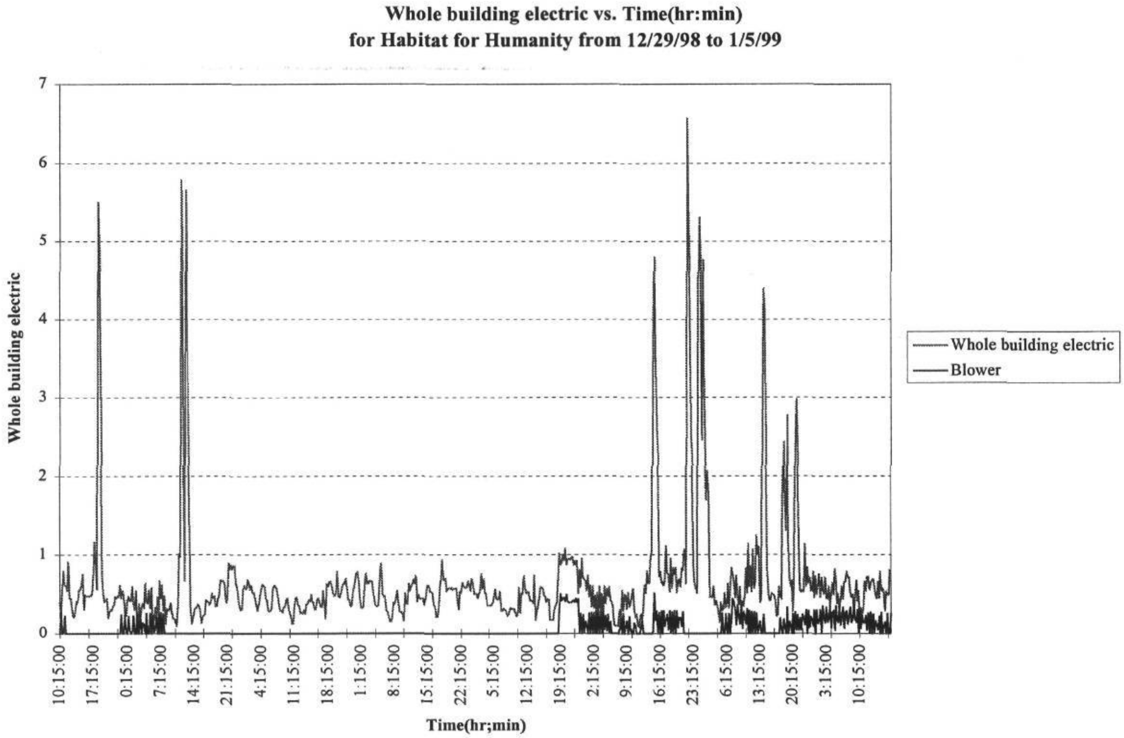

Fig. 11. This is the pattern of electric use for one week at the Habitat for Humanity house.

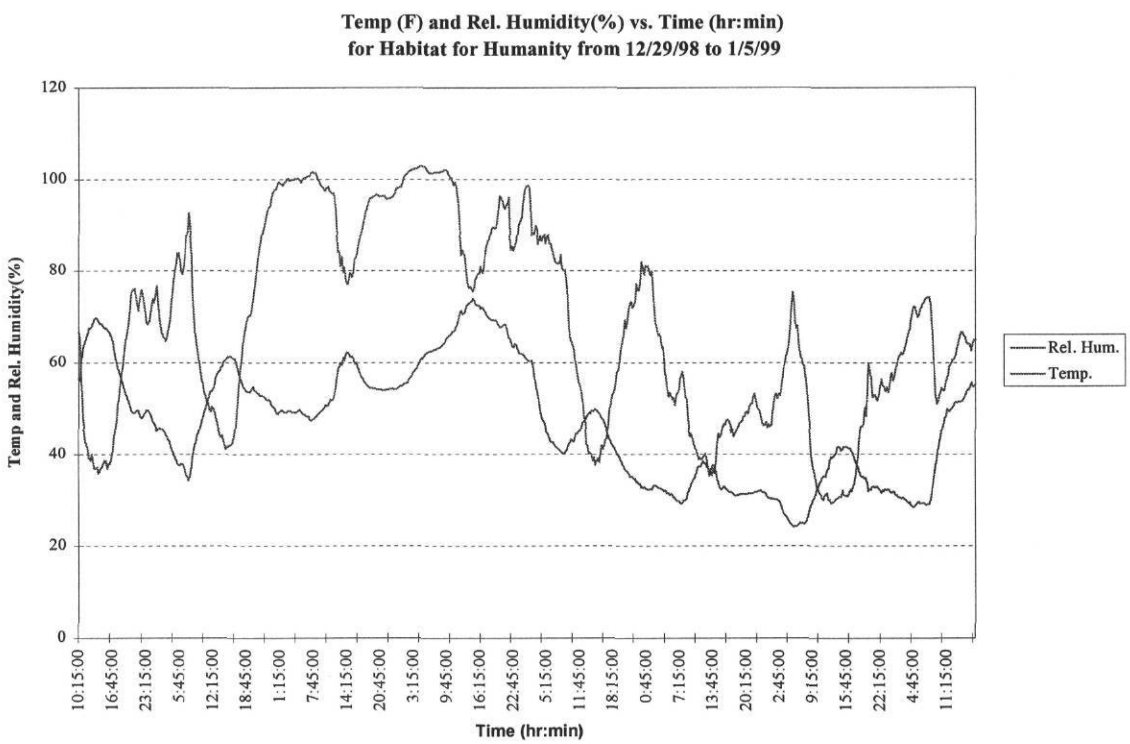

Fig. 12. Outdoor temperature and relative humidity measurements for one week at the Habitat for Humanity house.

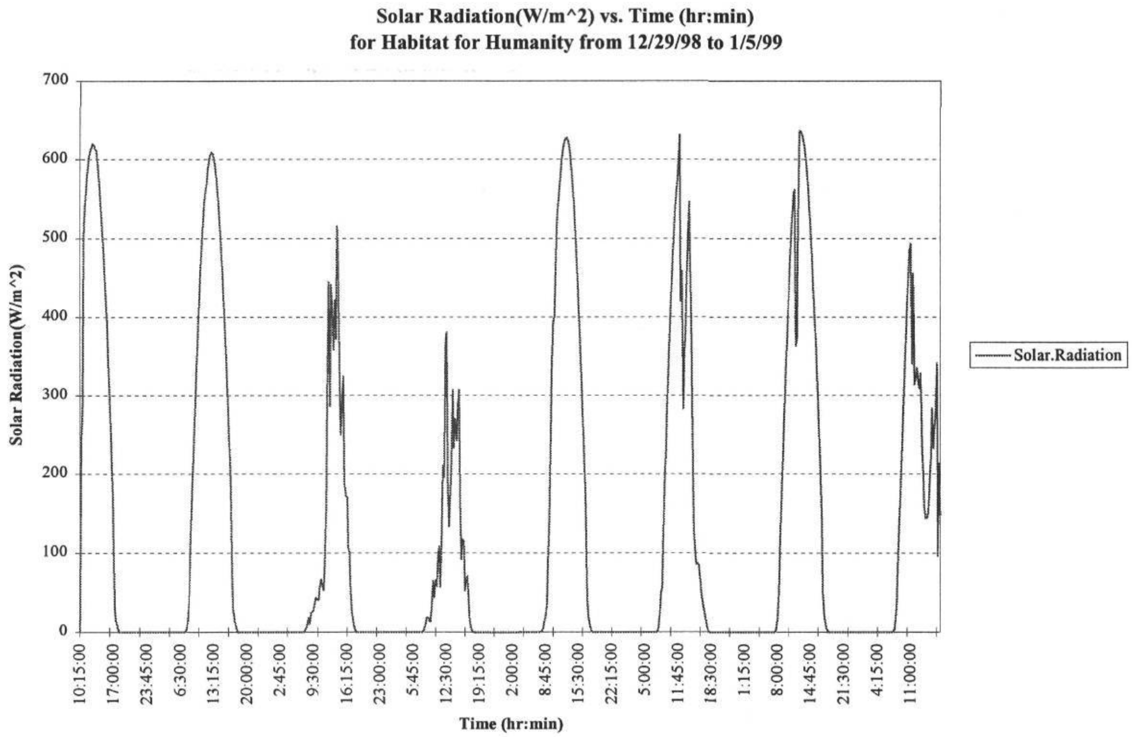

Fig. 13. Solar radiation measurements for one week at the Habitat for Humanity house.

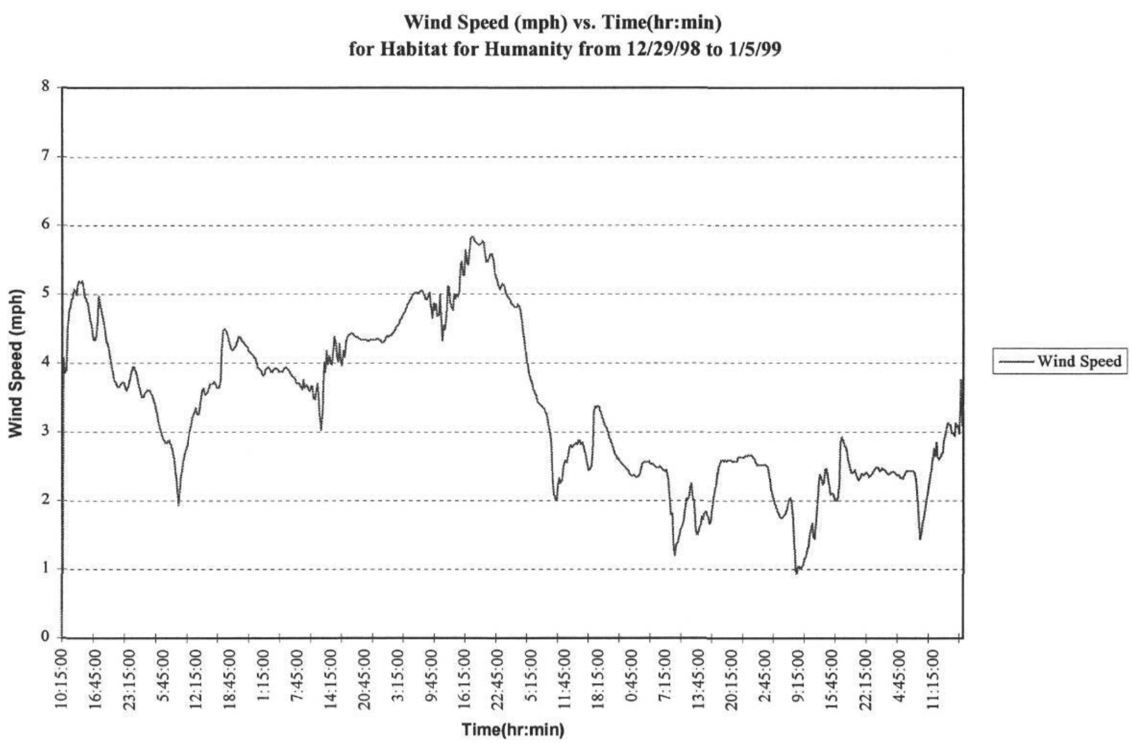

Fig 14. Wind measurements for one week at the Habitat for Humanity house.

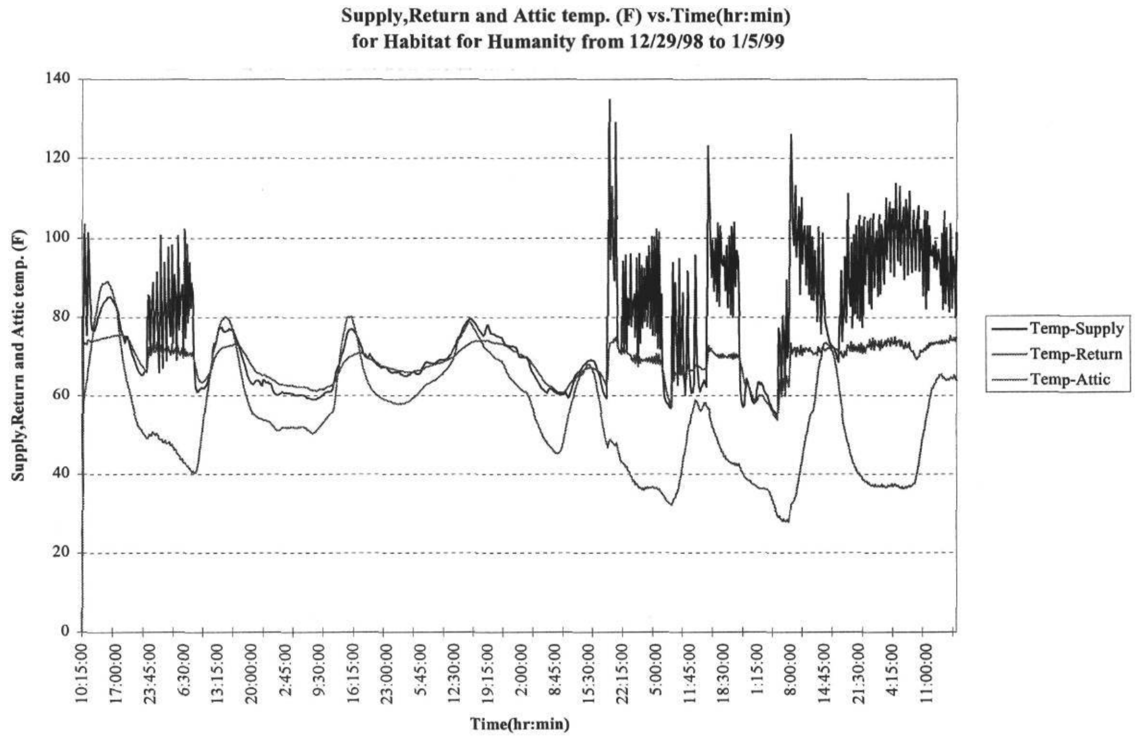

Fig. 15. Supply, return and attic temperature for one week.

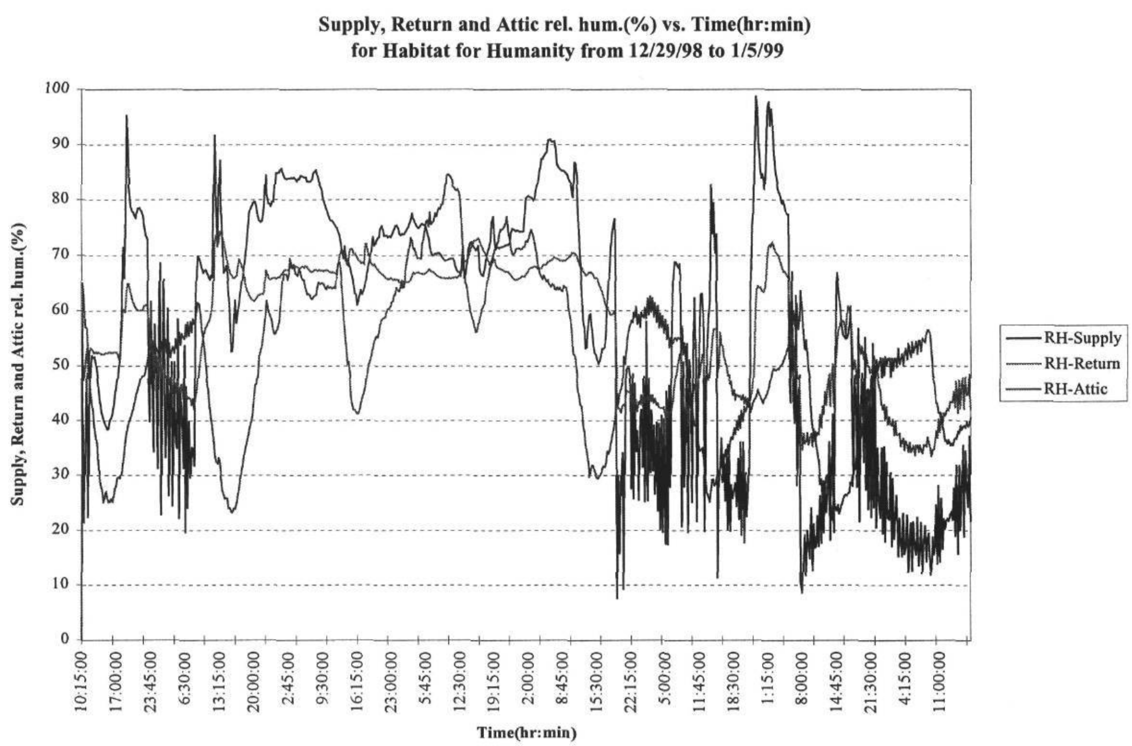

Fig. 16. Supply, return and attic relative humidity for one week.

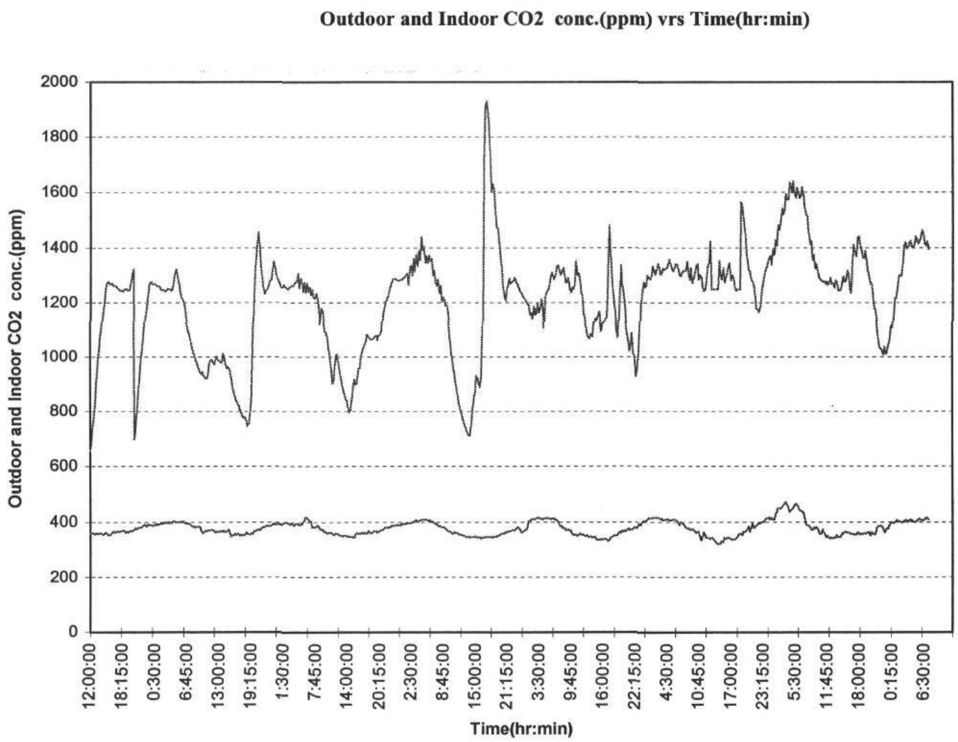

Fig. 17. Outdoor and indoor CO_2 concentrations for one week at the Habitat for Humanity house.

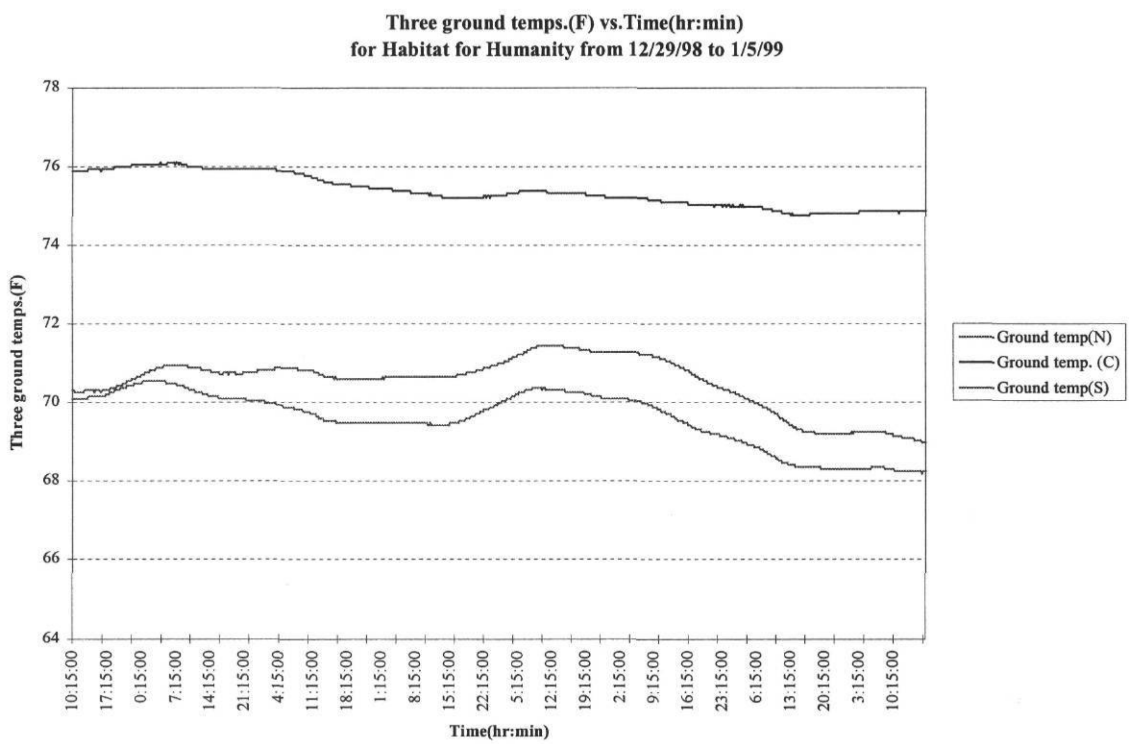

Fig. 18. Ground temperature measurements for one week at the Habitat for Humanity house.

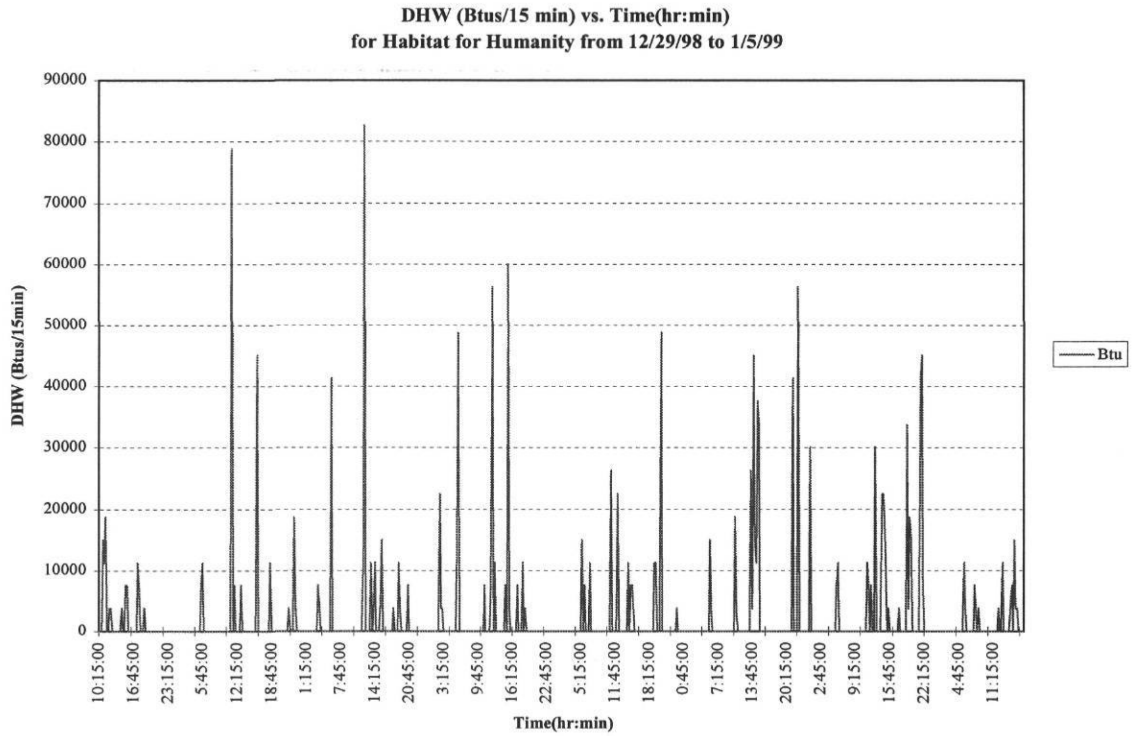

Fig.19. Btu measurements for the domestic hot water heater for one week.

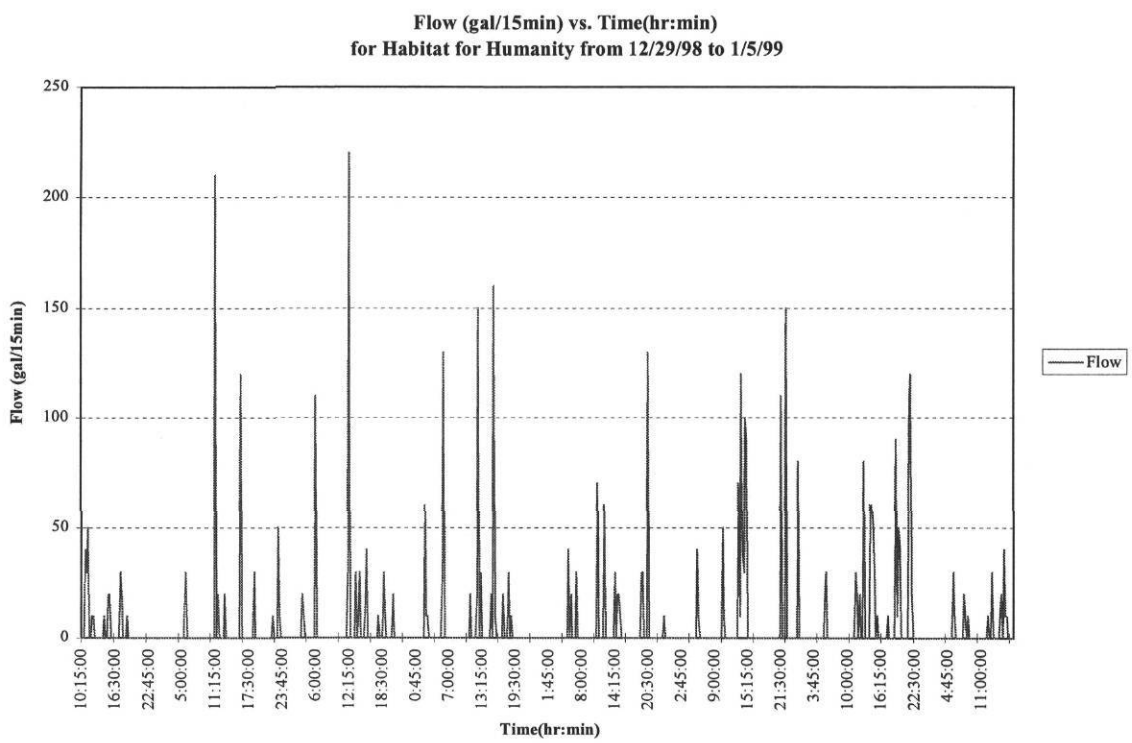

Fig. 20. Flow measurements for the domestic hot water heater for one week.

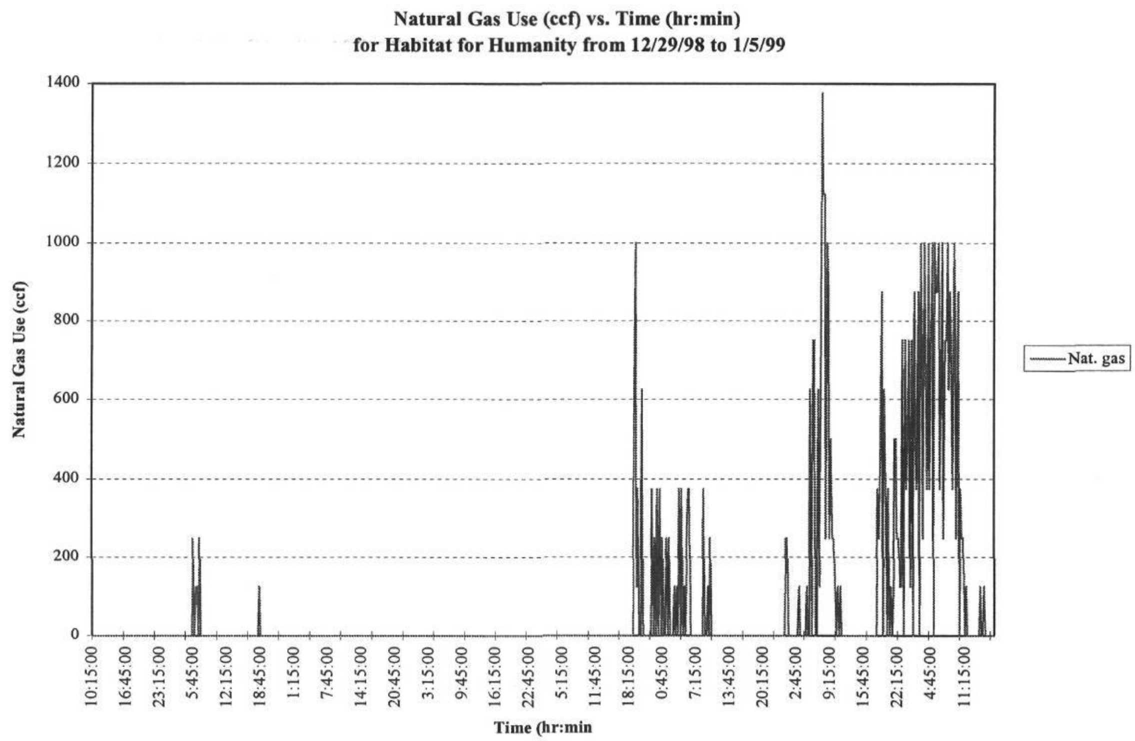

Fig. 21. Natural gas measurements for the Habitat for Humanity house for one week.

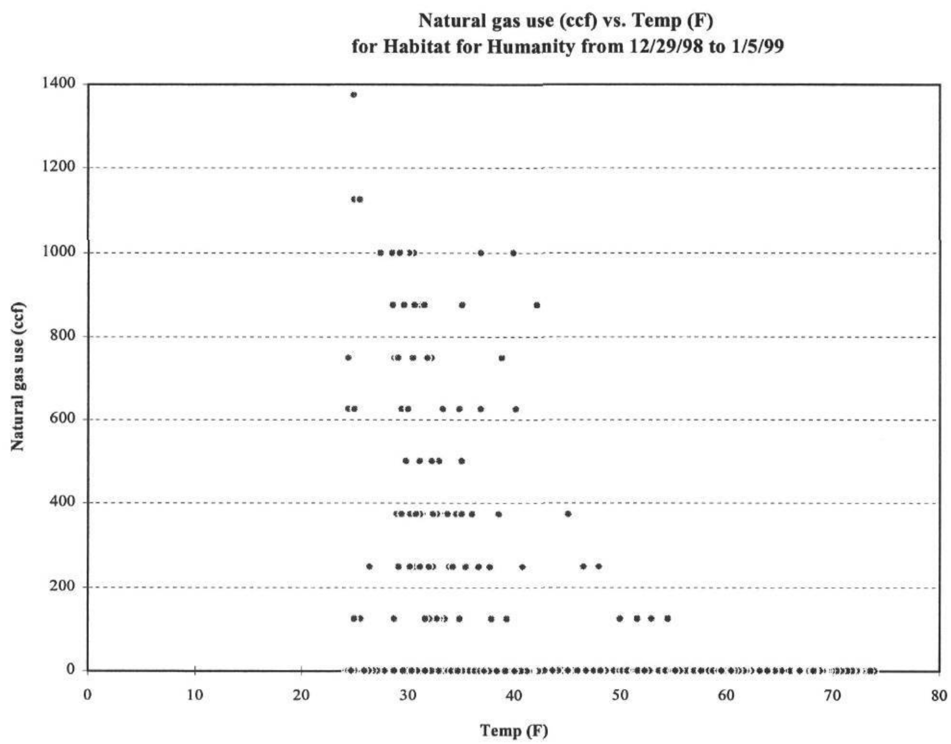

Fig. 22. Natural gas use versus outdoor temperature for the Habitat for Humanity house for one week.

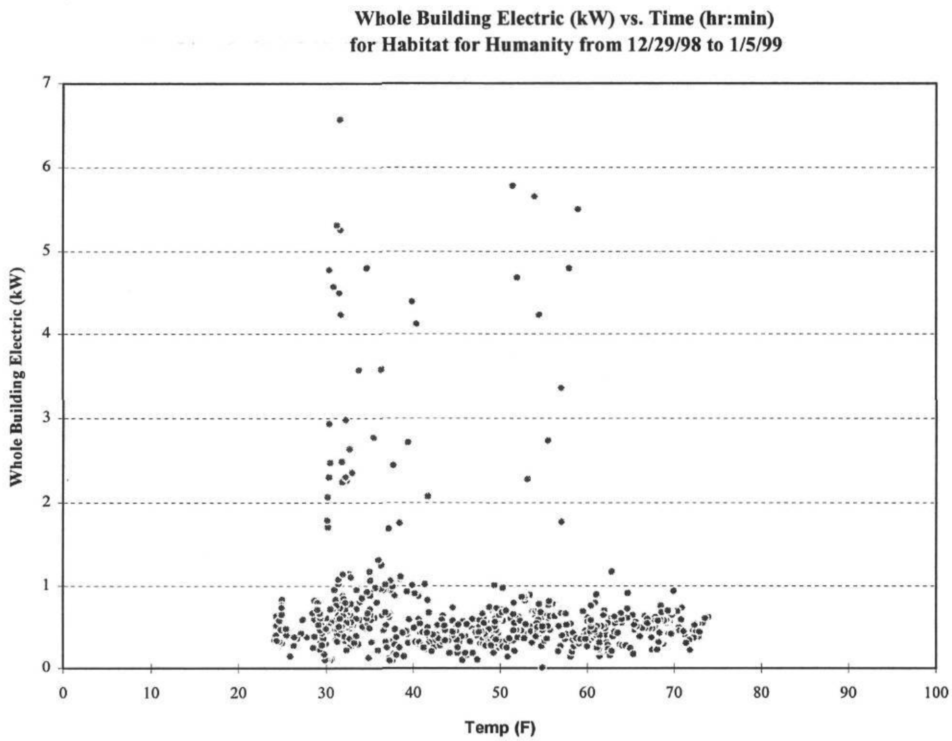

Fig. 23. Whole building energy use measured against outdoor temperature for one week.

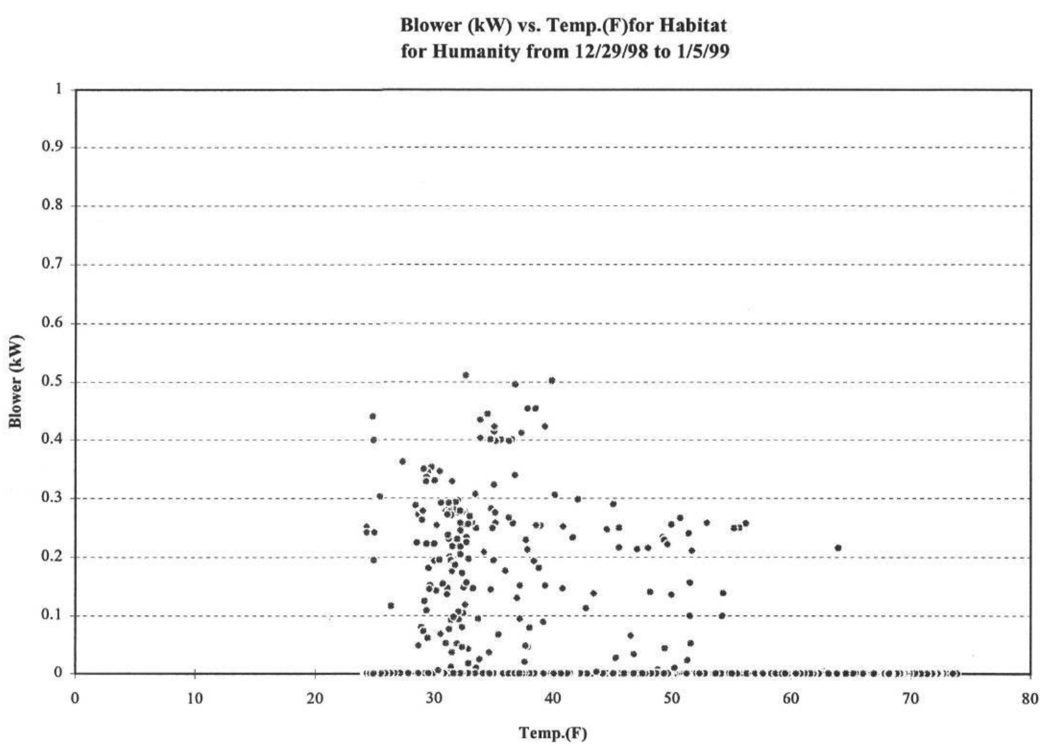

Fig. 24. The blower energy use versus outdoor temperature for the Habitat for Humanity house for one week.

Discussion of the Budget

Table 1. This table shows the budget for the project. The amount of money remaining in the project account is $3,416.76 of a total of $24,733.00. It is anticipated that this amount will be used to finance continued testing and develop of new experiments relating to indoor air quality, humidity and energy use of the case study Habitat for Humanity house.

Budget Outline	Estimated Total	Actual Total	Difference
Salary			
Graduate Students	$8,010.00	$6463.45	$1547.55
Other Employees	$2263.00	$1149.01	$1113.99
Services			
Supplies & Others	$1560.00	$1649.42	-$89.42
Equipment	$12,900.00	$11,371.96	$1528.04
Total	**$24,733.00**	**$20,633.84**	**$4099.16**

Table 1. Details of the budget